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SOME PRACTICAL COMMENTS ON THE DEVELOPMENT
OF ACTIVITY-EVENT FLOW NETWORKS

By

Lt. James W. Alstrom

Operations Analysis Office, Hq AFLC
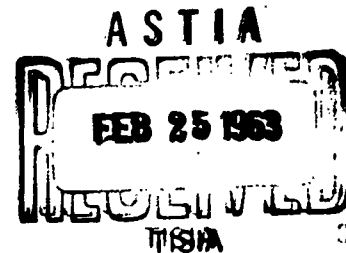
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SOME PRACTICAL COMMENTS ON THE
DEVELOPMENT OF ACTIVITY-EVENT FLOW NETWORKS

I.   Introduction

The most difficult step in the implementation of a PERT-PEP type of
management system is the development of an activity-event flow network which
represents the job to be accomplished. An activity-event flow network is a
plan showing the time sequenced steps needed to reach a stated objective,
such as the R&D, testing, tooling, establishment of a logistics system, etc.,
needed to make a weapon system operational. It is a graphical presentation
of the things to be done in the order they must occur, plus an identifica-
tion of significant beginning points and accomplishments. This paper is an
attempt to describe networks and their building blocks, and to set forth
some methods for their development. It is not meant to establish rigid pro-
cedures, but only to suggest methods and alternatives which, in the experience
of the author and others, have proved useful.

A network must be realistic, comprehensive, and include a proper level
of detail. Its development will usually be participated in by both managers
or technicians responsible for the tasks being networked, and by men familiar
with networking and with the operation of the PERT-PEP system. Often, the
network will cover areas in which the relationships and interactions between
activities have not been previously considered in anything approaching a
comprehensive manner, so that in effect the process of networking is the
process of setting down for the first time a complete program plan. In other
cases, come form of milestone or Gantt chart plan will precede the network,
but it will not have the activity and/or the interaction orientation which is
characteristic of a network. The plan often turns out to be either incomplete

or at least not specific enough to satisfy rigorous networking requirements. Thus, it is necessary to go through what usually turns out to be a long and difficult session of defining events and activities and their relationships over time. The results, however, will be a plan of unusual clarity, completeness, and usefulness in the areas of programming, status monitoring, and forecasting.

Flow networks are activity and activity-interaction oriented. This is a major improvement over the milestone system which concentrates on the points in time when various items are complete or available rather than the human and machine effort which makes up the activities which must be completed to reach the milestones. It is these activities - their objectives, manpower assigned, facilities, methods, etc. - which are truly under the control of management. It is also an improvement over the Gantt chart, which shows activities but either does not indicate their relationships (what must be completed before others can begin) or, at best, indicates most of the interactions simply as occurring at specified times after the beginning or before the completion of the activities concerned. These charts usually fail to identify specifically progress which must be made before the tie-ins between activities are either available or required. It is these concepts of explicitly specifying the activities and their points of interaction which is the backbone of networking - both in use and in construction - and it is quite important that they be kept constantly in mind.

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II. Definitions and Suggestions for Creating the Network Components

A. The Events

Events are points in time which indicate the beginning of or the completion of one or more activities. They are useful as status monitoring points, and as at least partial descriptions of the activities which are their basis. Often they may be points of decision, where alternatives are eliminated or chosen - or where the program might be discontinued. In many cases they may be simply "Begin Activity X" or "Complete Activity X." In other cases, they may represent the accomplishment or beginning of a significant phase of the total job, or the transfer of responsibility from one organization to another, and thus may be the completion or initiation of several activities. It is for this reason that the events by themselves cannot always specify all of the activities which are connected to them.

Events do not take time in themselves to complete - they either are, or aren't. They exist, or don't. One moment they have not been reached, the next they have been reached. As such, not only is a description of the event needed, but evidence of its existence must be identifiable. For instance, the event might be "systems budget estimates completed", and the evidence would be the release of the document by the responsible office. In order to be assured that the event is truly significant, it is wise to specify the evidence and the reporting office when initially describing the event.

B. The Activities

Activities are things being done, characterized by people using facilities over some period of time to accomplish a stated objective. Activities imply doing - preparing, researching, building, negotiating, deciding, testing, etc.

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Activities are the "flow" of a flow network, and it is this flow of human effort, materials, use of facilities, investment, expenses, and progress towards an objective, which can be controlled by the manager.

More basically, anything which takes time is an activity. Thus, the time required by transmittal of information or delays made necessary by regulations or contract provisions are properly shown as activities. Administrative decisions to begin an activity some time after it could have begun, approvals involving decision time, fabrication of a vehicle, development of an electronic component - all these are time consuming and are thus activities in the network.

The rigorous nature of the flow networks requires that the activities be independent. That is, activities occurring simultaneously must be performed by different people or organizations and require no inputs from each other. They must be able to take place independently of each other, and not require any inputs other than those shown by the network as feeding into the initiating event. Further, the activities in series with each other must also be independent - that is, the time which one takes should not effect the time which any of the following ones take - for the statistical mathematics used in combining times becomes invalid if this condition does not exist.

It is good practice to define explicitly each activity, as well as each event, as the network is developed, and to list the responsible office and the evidence of completion. Often they will be the same as for the event which signals the end of the activity, but when two or more activities lead into one event, the event cannot conveniently describe both. Some organizations using flow network management systems have not gone to this additional "bother", relying on the event to specify the preceding or succeeding activities. Consequently, they have to some extent lost the activity orientation which is so basic to the system, and have in addition created networks which are not as

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easily understood. There is danger in so doing that the network will be less

accurate and realistic than it would be if all activities are identified, for

the responsible people creating it will not have explicitly before them as

clear and concise a picture of the plan they are laying out. For the same

reason, the next higher level of management will find it less useful than it

could be to them for monitoring planning, etc.

C. Restraints or Zero-time Activities

The concept of a zero time activity or a "restraint" is also useful. This

is simply a specialized type of activity most easily identified by using a

dotted line on the network layout which constrains the beginning of a following

activity, or the completion of the event to which it leads by requiring that

the event from which it proceeds be completed first. However there is no

specific activity required between two events connected by a restraint. It is

often used to tie the completion of several activities to the beginning of a

single activity, or vice-versa.

This is shown in the illustration below, where events are shown as circles,

activities as solid arrows and restraints as dotted arrows. Events 1 to 3

might be the completion of a test airframe. engine, and guidance system; event

4 would be the beginning of the W/S assembly.
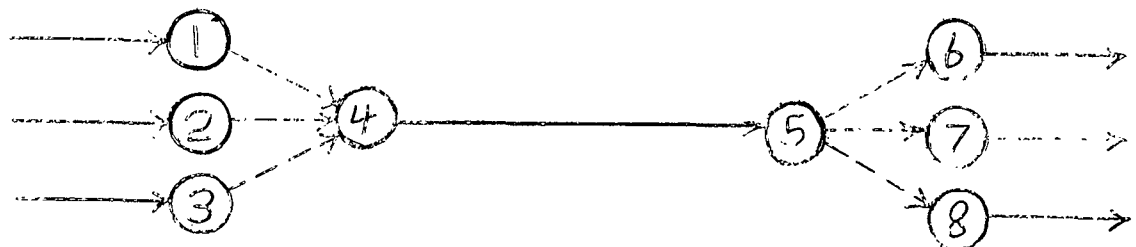
A more frequently seen example is:

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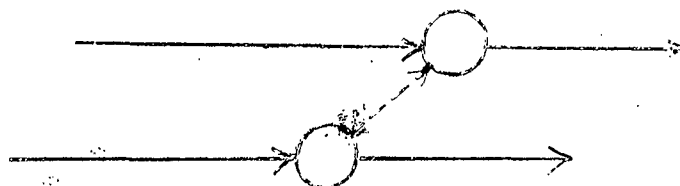
The restraint may also be used in exceptional cases when it is desired to indicate, by separate events, the ending of one activity and the beginning of the following one. This may be desirable in cases where the completion of one activity is of major significance, and where it is necessary to be quite sure that the following activity begins immediately as planned.

Although activity 2-4 (B) can begin upon the completion of activity 1-2 (A), there is no guarantee that it will do so. The addition of restraint 2-3 and event 3 insures that the beginning of activity 3-4 (B) is recognized as important and is reported upon.

D. Other Definitions

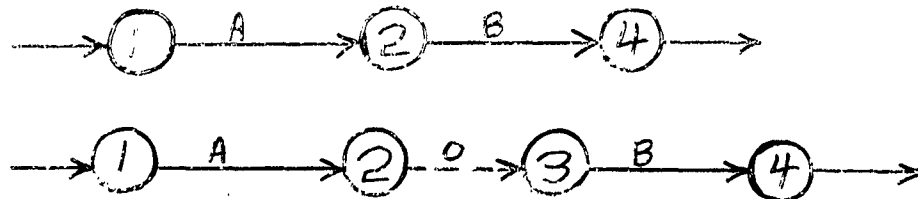A series of activities, which could be considered a small network in itself, is often referred to as a "task." A task can often be represented as one independent activity when summarized.

A milestone and an event are almost synonymous, but a milestone usually refers to a very important event. All events in a top level summary network might be milestones.

E. Less Rigorous Activity Definitions

It is sometimes difficult to identify the beginning and ending points of activities using the strict flow network criterion which states that an event is not completed until all activities leading to it are completed and that no activity leading from an event begins until the event is completed. Another difficulty lies in the assumption of independence, for often it is not useful to go to a level of detail which breaks out every point of interaction between

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two or more activities.

A convenient and sometimes necessary approximation in cases of this nature involves defining events and activities as "essentially begun" or "essentially completed." By this is meant that the greater part of the effort then begins (or ends), even though some work had started previously. It might be the point at which most of the people who are assigned to the activity begin their effort, or a point in time when enough of the work is accomplished so that following activities can begin. Although the network retains its strict activity-event interrelationships and restraints, the human input is allowed to retreat somewhat from the rigorous criterion, and to set down expected real world situations that simply cannot be stated except by approximations of some type. This method of networking areas where the beginning and ending points of activities are not entirely clear nor readily described should not be used as a generalized procedure, but should be reserved for those activities which have previously eluded the more rigorous approach. Extension beyond the minimum possible use would result in defeat of the purpose of networking - complete and exact planning.

The problem of independence arises when two (or more) tasks have many points of interaction, often of an information exchange nature. If networked rigorously, these would be divided into a very large number of short and overly detailed activities. One possibility for avoiding this is to combine the two tasks into one activity in the network, looking at it as a joint effort of the two groups or individuals involved. However, if the distinction between the two is desirable, and it is felt that the interactions will not be of a delaying nature, the two can be shown separately as two approximately independent activities. These situations should be noted for special surveillance so that delays occurring in the middle of one activity, due to delays in the other, can be identified rapidly.

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Begin Airframe Design → Design → Initial Parameters Available → Continue Design → First Drawings Released → Complete Design → Final Drawings Released

Begin Propulsion System Design → Design → Initial Parameters Available → Continue Design → First Drawings Released → Finalize Design → Final Drawings Released
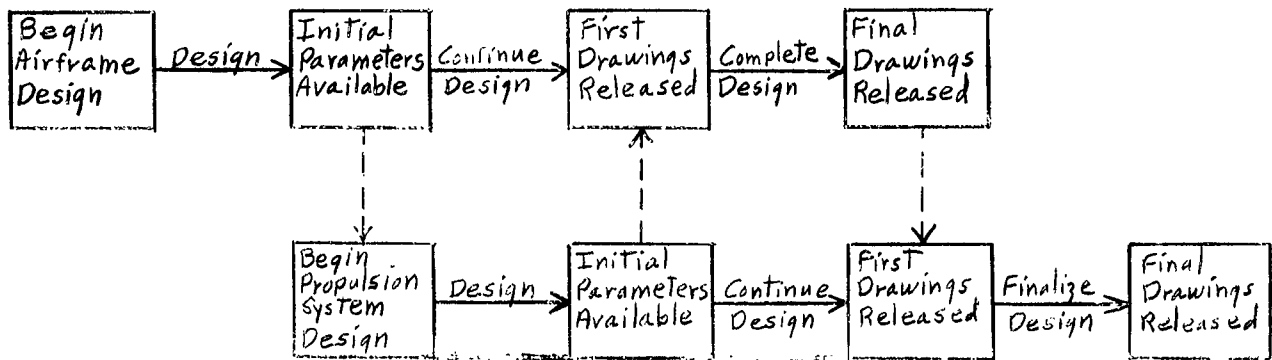
The dotted lines indicate information exchange. These could be elimin-
ated, leaving the two "approximately independent" activities of "design airframe"
and "design propulsion system."

F. <u>Forms of Expressing Event and Activity Names</u>

In order to avoid the confusion found in many milestone lists, and to
generally improve the clarity of presentation, considerable attention should
be given to the names of events and activities An activity implies doing
or action, and thus should be expressed as a verb form (develop, testing,
complete) which will not be confused with the beginning or completion point
of the activity. Events should be noun forms to express a <u>state of being</u>
(developed, tested, completed, begun): words which imply the passage of time
.. should be avoided. Each identifier should be concise, so that various
personnel with different backgrounds and points of view will interpret it in
the same manner. Strict adherence to these practices will be of help to
operating personnel in the construction of networks for it will tend to keep
them in a state of mind conducive to exactness and completeness. It will
make the job of evaluation less difficult for everyone concerned, and will
ease the job of extracting unambiguous major events ("milestones') for
summary networks or management reports.

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G.   A Few Suggestions Concerning the Graphics

The usual procedure for representing events is to use circles or boxes, although some organizations have resorted to a number of various shaped enclosures to represent various types of events (colors may be used, but their reproduction is difficult). Each subsystem might use a different shape, or each A.F. management function might be shown differently (research, logistics, GSE, testing, etc.). Another procedure involves laying out regularly spaced boxes to cover an entire page, reproducing these worksheets, and filling in and connecting those which are convenient.

Activities are shown as solid lines, or sometimes as double lines if they are on or near the critical path. Dotted lines distinguish the restraint. It is preferable to lay out the network in such a way that all arrows flow from left to right, both for clarity to the users and to reduce reproduction errors.

Large pieces of paper are needed for networking, for each event and each activity must be defined using several words, and responsible agencies and times estimates must be included. As an example, one network recently constructed used squares $1\frac{1}{2}''$ on a side for events, left a minimum of $2''$ between events for activity lines, and placed a maximum of fifty events on a piece of paper, 24 by 36 inches.

Time scales should be avoided until networks are approved and ready for presentation. A very clear presentation then results from laying out the events on a time scale according to their calculated Expected Time, and differentiating slack time from activity time by using different types of lines. However, a complete new drawing is needed each time a change occurs in an Expected Time.
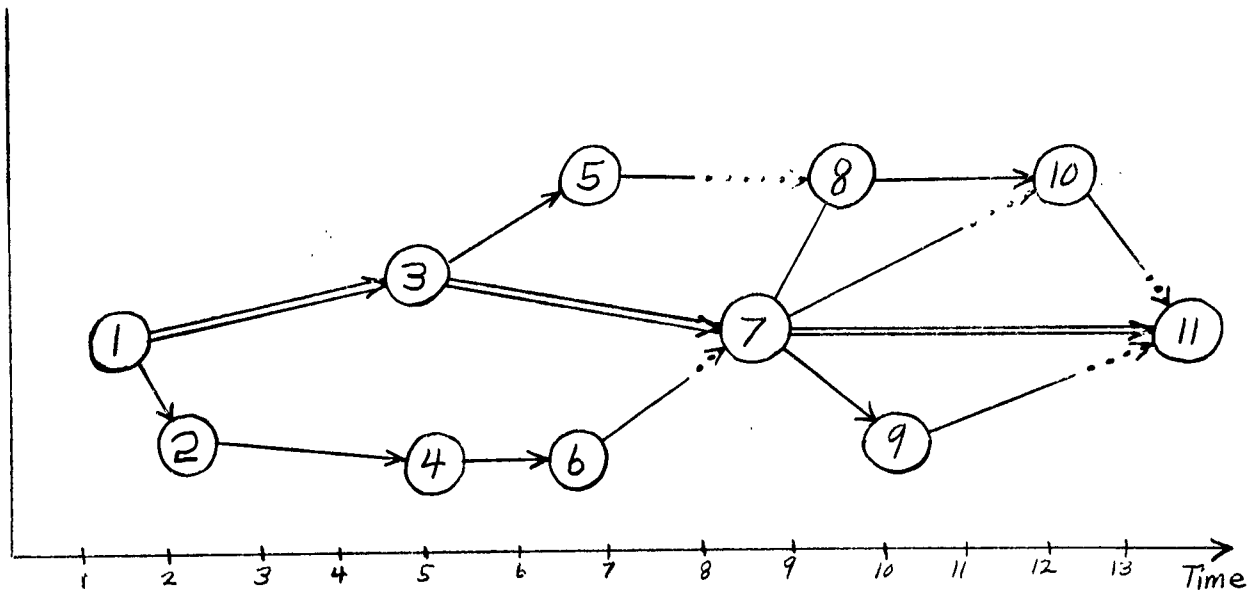
======================= critical path

———————————— activity

• • • • • • • • • • slack

The horizontal length of each
line is time scaled. The events
appear above their calculated
Expected Time.

Slack may be associated with a slack path of several activities (such as
1, 2, 4, 6, 7; or 7, 9, 11; or 3, 5, 8; or 7, 8, 10, 11) or with a slack "path"
of one activity (such as 7, 10; or 9, 11). In any case, the slack is part of
the entire path and not (necessarily) part of one activity.

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A.   Types of Networks

Two types of networks which have quite different management characteristics have evolved from PERT-PEP system developments. One is made up of "hardware oriented" activities such as research and development, tooling, production, testing, etc. - anything which relates directly to physical progress on the job to be done. The other is made up of "management activities" such as planning, funding, approving, negotiating, inspection, etc. - all of those activities which management must accomplish in order to keep the "hardware activities" continuing on schedule.

· It may seem that these two "types" of networks are not separate at all, but are really only parts of one network describing the total job to be done. This is of course true. All of the activities in each network have to be accomplished, and any activity in either one could be the one which delays the final objective. Approvals and decisions and various sorts of documentation are as important to the completion of the overall job as are research and fabrication and delivery of GSE.

However, most networks presently in use concentrate almost entirely on the "hardware activities" (develop, test, tool, produce) to the exclusion of the "management activities" (fund, decide, approve, negotiate). A truly useful management network must include not only "management activities", but also portray in some way the hardware (mostly contractor) activities; as such it can be made up in-house for Air Force management use. Of course, the contractors may have more detailed networks of the hardware tasks available for their own use and as a backup for the A.F. plan, although only first level summaries of these may be kept on file at the Air Force management office. The realization

that both types of activities must be included is quite important, though, especially since experience to date indicates that the initial networks for any system will usually be a more or less summary picture of the hardware job. Before full potential of the system can be realized by Air Force management, the management picture must be developed. (See "Weapon System Development Network," #1 & #2, prepared by the Operations Analysis Office of Hq AMC, 2-61).

B. Detail and Summary Networks

The detail needed for a network depends upon the level of management which will make active use of it. Top management will want and need only a gross summary, while those in charge of the actual day to day tasks can use a network showing every significant step involved. In any case, each network should be complete, in that it covers the entire project without omission - to summarize does not mean to omit!

In a summary network, each activity represents what may be several or even a whole network of more detailed activities. For instance, an Air Force high level management network may show an activity beginning with an R&D contract being signed and ending with a mock-up inspection. The SPO would want more detail, and the contractor would need a rather large network for this task. However, each level of network is comprehensive, as shown in the following figure which illustrates complete coverage of the detailed tasks by various summary levels of networks:

Hq. USAF

Hq. AFSC

SPO

Contractor
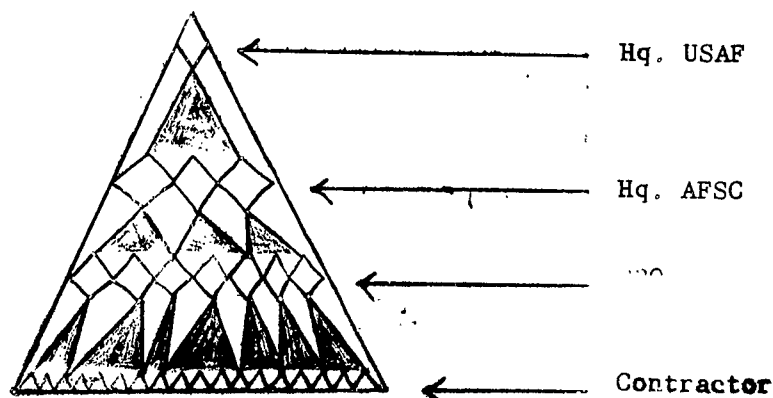
The definition of "significant activity" for any level of interest includes factors such as expected difficulty of the task, length of time it will take, the magnitude of accomplishment its completion implies, how many other activities interact with its beginning or completion, etc. This will vary from activity to activity and from network to network, but one common factor is the need to consider the network as a monitoring as well as a planning tool. Management may decide that it is necessary to check on the progress of activities within a given task at least every "X" weeks, so that frequency of reporting may partially govern activity lengths. In this case, the "events per reporting period" times the length of the entire job (in reporting periods - possibly two week units) would provide an estimate of the network size needed. However, great care must be taken not to create artificial, unreportable, or insignificant events in an attempt to meet frequency of reporting criteria. Activities can, if necessary, have their remaining time re-estimated every "X" weeks without a significant event having occurred.

As more and more detail is included in a network, it becomes easier and easier to show a true picture, for interactions are all included explicitly. Summarizing a network may become quite difficult when large segments of it, which are logically reducible to one activity each, have interactions from internal points. In this case, either more than one activity may be used, or "weak" interactions may be neglected as discussed earlier in this paper (page 7). Another possibility is to summarize one of the networks (if one has no internal interaction points) as one activity in the other network. The following figure illustrates this:

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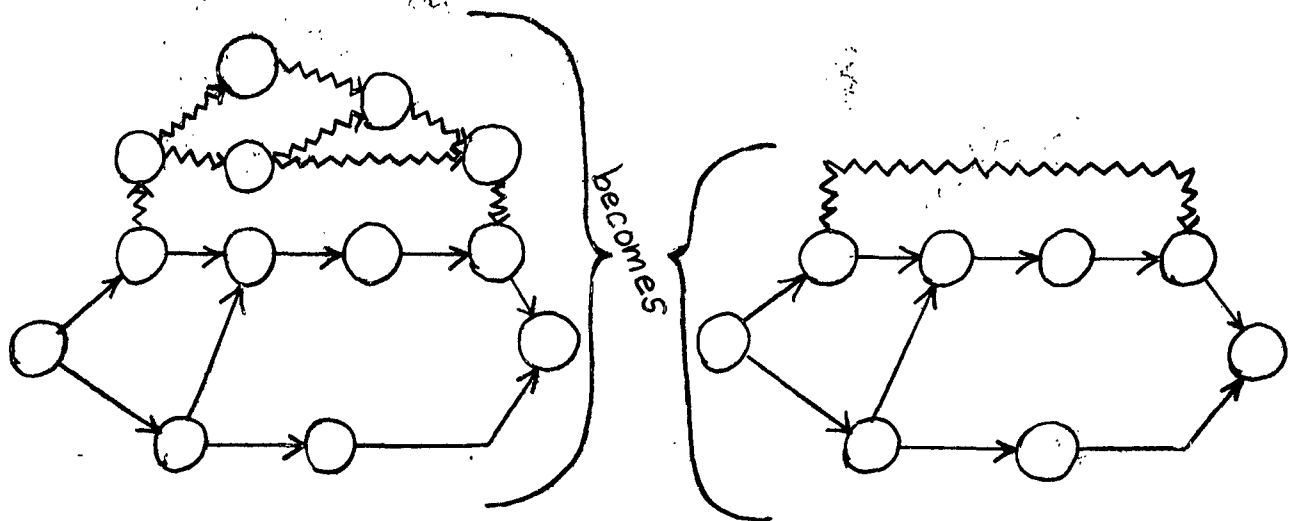
C. Starting to Construct the Network

There are several ways to attack the construction of the initial network for a program. In some cases there has been some previous planning so that a list of milestones or possibly a typical summary network may be available. In other cases, the network may be constructed using nothing more than the knowledge of a group of people who are familiar with the objectives or requirements of the project, and who have had experience in the functional areas involved.

If the latter situation exists, where there is little or no prior comprehensive program planning, one may start at the beginning event (program start) or at the ending event (program completed). Of course the beginning and ending points must first be well defined, so that all of the networking participants have a common understanding concerning the current status and the objective to be reached. In any case, people must be present who have (among them) a total picture at a summary or overall planning level of the entire project, for this group approach is likely to be more economical of time and effort than would be an approach involving separate networking sessions with

many individuals. Later, individual areas (one or more activities) may be selected for more detailed treatment and specialists in the area will be consulted. This "top level down" approach seems to be the most desirable, as it quickly produces an integrated picture of the entire project and provides a logical basis for deciding how much of the program must be detailed down to what level. Starting at a detailed level and summarizing for higher management may result in unneeded work, too large a network for the entire project, and unnecessary delay in presenting an integrated plan to management.

If one starts at the beginning, the logical question "what can come next" is asked as each event is completed. As an activity and its concluding event is added, the question "what else must be done in order to reach the event" is asked. This procedure may continue along the progress of one given functional area, reach the final objective, and then start again along another more or less independent functional area. Or, all areas may be developed concurrently. The latter is more difficult, because the advantage of following one train of thought is lost. However, the former requires notation at each event of possible interactions with other functional areas, so that connecting activities or restraints may later be added.

If one starts at the final event, the question is "what activity" or "what other activities must be completed" before this event is completed. This avoids the question of what <u>can</u> occur now, and sticks to the more objective question of what <u>must have</u> occurred. Often there are a number of activities for which all the prerequisites have been completed and which <u>could</u> begin at a given event. However, each manager has a concept of "good management" which dictates his mode of operation, and within certain physical or logical limits (you can't

test a W/S before the test facility is ready), he will sequence his activities in a way which will conform with his ideas. The "must have occurred" question will result in an initial network free of these management biases, and presents a more objective picture which may then be modified as needed. However, experience has shown that this method of working from the rear forward may tend to result in more detail than desired, for the operating people may try to include (as a separate activity), literally every minute detail needed for the occurrence of an event.

Another approach which has been found to be successful entails the use of a simplified Gantt bar chart. Each major area of activity (such as each subsystem, or testing, or spare parts logistics) is represented as an approximate time phased bar on a time scale chart. Leave the bars far enough apart so that boxes (events) may be added along each one. Once the major areas are identified and represented on the familiar Gantt chart, the time scale is removed and major events are identified and added along each of the activity bars. Interactions (usually restraints) between them may be easily added at the same time the events are identified. Some portions of the bar will be enlarged into several activities or even a small sub-network on the first time around, but in general it is easier to put the entire chart into network form at a gross summary level before attempting very much detailing.

Another approach may be taken to the development of a project network if a milestone list has been previously prepared. In this case it may still prove helpful to start by assembling a group whose knowledge encompasses the entire project; but the prior preparation of a network by the PEP staff, followed by networking sessions with either individuals or groups, has been found to be a reasonable approach. In either case, to attempt to go directly from the list to a flow network may be quite difficult because of the lack of an activity orientation in the list, but an intermediate step can smooth the way.

A "dependency network", showing the relationships of the events, may be constructed by laying out the milestones with connecting lines showing only what milestones must be reached before others can be reached. All of these lines, none of which are at this step identified as activities, may not necessarily turn out to be major activities - some will be restraints and some will be minor activities needed to accomplish an event for which the major activity was not shown on the dependency network (minor or major in the sense that the time and effort spent on them is small or large). The figure illustrates this:
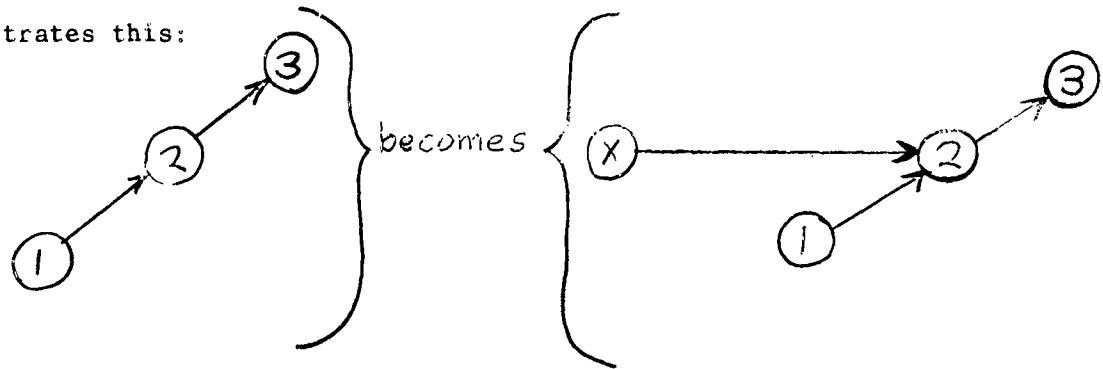
If dates (scheduled or otherwise) have been assigned to the milestones, laying them out along a time axis will facilitate creation of the dependency network. This axis should be removed before identifying and adding activities, in order to prevent identification of them with previously set milestones and backoff times.

The next step is to list the activities (along with the organizations which accomplish each one) which are required to achieve each of the events. These activities may then be located on the chart as an existing line, or added as a line and arrow leading to the event. A logical beginning event must also be identified, although this may be a management choice between several equally possible alternative events which might trigger off the activity.

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The various methods of laying out the network - starting at the first event or the ending event, using a simple Gantt chart, laying out a dependency network from a milestone list - all have one common tie. That is the desirability of starting with a summary level, non-detailed picture from which further networks can be developed if necessary. The approach taken will depend upon how much previous planning has been done and upon the preference of the networkers.

D. Alternate paths.

When there are two or more possible approaches to an objective, the networks will be faced with an event which initiates one or the other of the choices of activity paths. A flow network will not recognize "or", so either the person responsible for the job must choose the most likely course of action, or the longest of the several paths should be used. The latter is the conservative approach, giving the longest time span which might be expected, but the network should be modified as other paths become much more probable or as the originally chosen one is ruled out.

It is neither necessary nor desirable to try to arrive at time estimates
at the same time as the identification of the activities and their relation-
ships is being accomplished. It is best to remain oriented towards the jobs
to be done rather than complicating the matter with factors of manpower,
facilities, time, etc. In addition. the people who lay out the network may
not necessarily be the ones who have the most specific knowledge of the magni-
tude of each job, or they may wish to consult with others before stating a
figure. When the network is complete, each responsible organization or office
can then examine their parts of the overall project and arrive at time esti-
mates.

The times are not to be confused with dates. Only flow times -- times
to accomplish a given activity once it has been started -- are wanted. Any
identification with pre-set schedules or backoff times from other activities
is to be avoided, for it nullifies one of the major advantages of network pro-
gramming -- factual time flow estimates for specifically identifiable indepen-
dent activities. Realistic schedules are one of the outputs (not inputs) of
the system. It has been suggested that only small portions of the network
be made visible at a time, and that the networker jump around the network in
random order after starting somewhere in the middle, when soliciting the time
estimates.

The time estimate for each activity consists of three separate statements,
and results in a measure of the uncertainty involved. It may be difficult at
first to convince people to make the three estimates, but experience has indi-
cated that they will welcome the chance to express their uncertainty in quanti-
tative terms as soon as they understand the concepts involved. Most activity

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involving intellectual effort does not lend itself to exact prediction of the flow time (production line or machine limited operations are of a different nature), and it is often the case that exact schedules are met only through relaxation of effort or, more often, last minute speed-ups.

Time estimates for quantifying uncertainty, i.e., developing probability estimates, are made assuming some given, pre-planned outlay of effort. One planned workforce (which may remain constant or may build up and decline according to a schedule), number of work hours per day and days per week, facility availability, budget, etc., is assumed when making the three estimates, and any change in any of these necessitates three new estimates.

The first figure requested is the most likely time. This is the time which constitutes the "best guess" of the estimator, given the assumed conditions and average luck. The second figure is an optimistic time, given the same conditions but unusually good luck and rapid progress. This time is to be realistically obtainable, but probably wouldn't happen more often than two or three times if the activity were to be repeated a hundred times under the same conditions (assuming each time that it had not been done before). Lastly, a pessimistic time is requested. Except for fires, floods, strikes, and the like, rather bad luck is assumed. The activity might reasonably take this long two or three times if repeated a hundred times (each time with no learning, or experience factor). The three estimates are placed in parenthesis along the activity line and next to the description (O, ML, P).

The three estimates are used to arrive at quantitative measures of the time uncertainty involved in the project. Statements about the probability of meeting schedules and other worthwhile information for management can be derived from them. Further, their use keeps an activity manager from being forced to state and work with a rigid time limit which he knows may not prove

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to be very realistic.

Even though it is assumed that the time estimates were given by the people most qualified to make them -- people at the lowest level who have full knowledge of the activity -- they must not be accepted uncritically. Management wants to derive the best possible picture of the entire project, and it would thus not be wise to incorporate times which responsible individuals in the networking groups, or in management, felt were unrealistic. Some adjustments can be made, if justified, in order to arrive at the best possible overall picture. Of course, both sets of estimates may be tested when there is a disagreement, in order to see if there is a significant difference in the completion time for the whole project.

V. Conclusion

The above comments, suggestions and caveats arise from the author's experiences during a number of network development sessions. They are not designed to set down a rigid set of procedures, adherence to which will absolutely guarantee a successful network. Rather, they are meant to be helpful suggestions to be applied where appropriate. The author welcomes additional comments from people who have had experience in networking which will either support those in this paper, add to them, or provide reason to delete them.